XIV. LINGUISTICS*

Prof. R. Jakobson
Prof. A. N. Chomsky
Prof. M. Halle
Prof. Y. Isami
Dr. G. H. Matthews
Dr. Paula Menyuk
Dr. K. Wu
T. G. Bever
S. K. Ghosh
Barbara C. Hall
J. J. Katz
R. P. V. Kiparsky
S.-Y. Kuroda
D. T. Langendoen
T. M. Lightner
P. M. Postal
C. B. Qualls
J. J. Viertel

A. THE NATURE OF A SEMANTIC THEORY

As an investigation in semantic meta-theory,[1] this report describes the abstract form of a semantic theory (or description) of a natural language: the form of the dictionary entries, the rules that project the lexical meanings expressed in dictionary entries onto sentences in the form of sentential meanings, the relation of such rules and dictionary entries, both to each other and to the grammar of the language, and the notion 'sentence meaning'. A meta-theory for semantic theories is needed to inform the field linguist of the types of semantic facts for which to look, the most revealing and succinct way to arrange them, and that which can be said about the semantic structure of the language based upon such facts in such an arrangement.[2]

In our paper "The Structure of a Semantic Theory" (henceforth we shall refer to this publication as "SST"), Fodor and I show that a semantic theory of a natural language has as its fundamental aim the construction of a system of rules which represents that which a fluent speaker knows[3] about the semantic structure of his language which permits him to understand its sentences. The idea behind this conception of a semantic theory is that such knowledge takes the form of recursive rules that enable the speaker to compose, albeit implicitly, the meaning of any sentence out of the familiar meanings of its familiar elementary components. This idea has the following two-part rationale. First, the most salient and impressive fact about linguistic competence is that a fluent speaker can understand a sentence of his language even though he has never previously encountered it. In principle,[4] he can understand any of the infinitely many sentences of his language. But, since at any time in his life the speaker can have encountered only an exceedingly small, finite subset of the infinite set of sentences of his language, and, moreover, his storage capacity is finite, we can conclude that the speaker's knowledge of the semantic structure of his language takes the form of a finite set of recursive rules that fix a meaning for each of the infinitely many sentences of his language. Second, since a speaker's understanding of the sentences of his language also depends on his knowing sufficiently the meanings of their elementary components, the lexical items in the vocabulary of the language, we can conclude that the meaning that the rules fix for a sentence must be a compositional function of the antecedently known meanings of its elementary components, the lexical items appearing

*This work was supported in part by the National Science Foundation (Grant G-16526); in part by the National Institutes of Health (Grant MH-04737-02); and in part by the U.S. Air Force (Electronics Systems Division) under Contract AF19(628)-2487.

in it. Hence, a semantic theory of a natural language must contain rules that explicate the compositional function that determines how a speaker utilizes the meanings of the lexical items in a sentence to understand what that sentence means. If a semantic theory is not adequate to explicate this function, it cannot represent the speaker's knowledge of the semantic structure of his language.

In SST, we proposed that a semantic theory consist of two components. First, a dictionary that provides an entry for each lexical item of the language which, in some sense, gives the meaning of the entry. Second, a finite set of what we called "projection rules" that use lexical information supplied by the dictionary entries for the lexical items in a sentence and information about the sentence's syntactic structure supplied by its grammatical description in order to assign a semantic interpretation to the sentence.

Since information about a sentence's syntactic structure will be needed to assign a semantic interpretation to it, we found it convenient to let the output of a grammar be the input to a semantic theory. In this way, each sentence considered by a semantic theory is represented as a concatenation of morphemes whose constituent structure is given in the form of a hierarchical categorization of the syntactical parts of the concatenation.[5] The sentence The boys like candy is represented by the concatenation of morphemes the+boy+s+like+candy which is hierarchically categorized as follows: the whole string is categorized as a sentence at the highest level of the hierarchy; the+boy+s is categorized as a noun phrase, and like+candy is categorized as a verb phrase at the next level of the hierarchy; the is categorized as an article; boy+s is categorized as a noun; like, as a verb; and candy, as a noun; and so forth on the next and lower levels of the hierarchy. Following Chomsky, we can represent such a categorization in the form of a labelled tree diagram in which the notion 'the sequence of morphemes m belongs to the category c' is formalized by the notion 'm is traceable back to a node labelled c'.[6] Calling this element of the structural description that the grammar assigns to a sentence its "constituent structure characterization," we have the constituent structure characterization of The boys like candy given in Fig. XIV-1.[7] Therefore the input to a

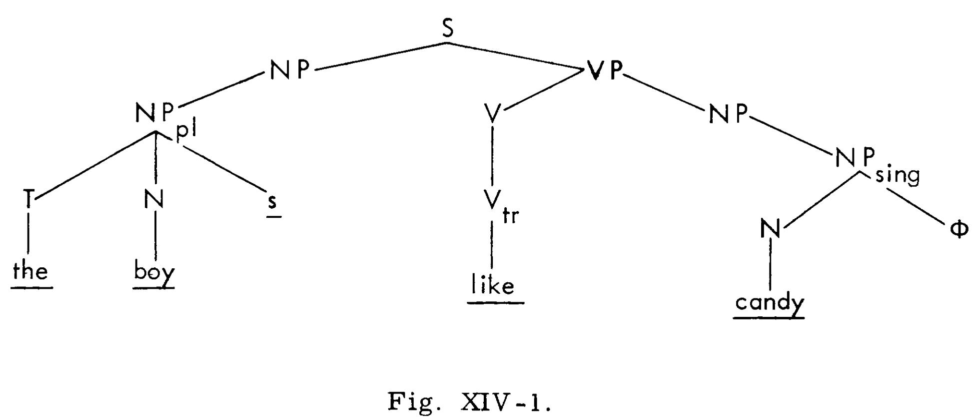


Fig. XIV-1.

semantic theory is sentences thus embedded within their constituent structure characterizations, together with any further grammatical information that an optimal grammar will supply about them.[8]

A semantic theory takes, one after another, the discrete outputs of the grammar and operates on them in a way that matches what a fluent speaker does to obtain his understanding of the sentences. This way of conceiving of the operation of a semantic theory provides a basis for explaining how a fluent speaker applies his stock of lexical information to apprehend the meaning of each new syntactically well-formed arrangement of lexical items that he encounters. Clearly, a semantic theory can provide such an explanation only if its projection rules assign each sentence a semantic interpretation that represents the manner in which a fluent speaker employs the syntactic structure of the sentence to determine its meaning as a function of the meanings of the sentence's lexical items. Hence, we must consider just what a semantic interpretation ought to tell us about a sentence.

The semantic interpretations produced by a semantic theory for the sentences of a language constitute the theory's description of the language's semantic structure. Since a fluent speaker's knowledge of the semantics of his language manifests itself in his verbal performance, a semantic interpretation of a sentence ought to tell us whatever the speaker implicitly knows about the sentence's semantic structure that enables him to carry on his verbal performances. Thus, the fundamental question we asked in SST about the speaker's verbal performance was "What does the speaker do that manifests his knowledge of the semantic structure of his language?" We answered that he differentiates sentences that are semantically acceptable from those that are semantically anomalous, he recognizes ambiguities stemming from semantic relations in a sentence, he detects semantic relations between expressions and sentences of different syntactic type and morphemic constitution, and so forth. On the basis of this answer, we concluded that the semantic interpretations produced by a semantic theory must mark as semantically acceptable and anomalous those sentences that the speaker differentiates as acceptable and anomalous, mark as semantically ambiguous those sentences that the speaker regards as such, mark as semantically related in such-and-such a fashion just those n-tuples of expressions and just those n-tuples of sentences that the speaker detects as so related, and so forth. Otherwise, we argued that the semantic theory cannot claim to represent the speaker's semantic knowledge. For example, a semantic theory of English would have to produce: a semantic interpretation for <u>The bank is the scene of the crime</u> that marks it as semantically ambiguous; semantic interpretations for the sentences <u>He paints with silent paint</u> and <u>Two pints of the academic liquid!</u>[9] that mark them as semantically anomalous; semantic interpretations for <u>He paints silently</u> and <u>Two pints of the muddy liquid!</u> that mark them as semantically acceptable; and semantic interpretations that mark the sentences <u>Eye-doctors eye blonds</u>, <u>Oculists eye blonds</u>, <u>Blonds are</u>

eyed by eye-doctors, etc. as paraphrases of each other but mark Eye-doctors eye what gentlemen prefer as not a paraphrase of any of these sentences.

To finish describing the conception of a semantic theory developed in SST, we need only characterize the notions 'semantic interpretation', 'dictionary entry', and 'projection rule'. However, it is important to point out that our characterization of these notions must be such that the semantic interpretations, dictionary entries, and projection rules of a semantic theory of any natural language will be specified formally, i.e., the application of the projection rules will be determinable solely on the basis of the shapes of the symbols in the strings to which they apply and the operations that the rules affect upon these strings will be mechanical. The degree to which a semantic theory is not formally specified is the degree to which the fluent speaker's linguistic knowledge, or his intelligence and ingenuity, are needed to determine whether or not the projection rules apply in certain cases and to determine what operations these rules affect when they apply. Hence, to require that a semantic theory of a natural language be fully formal is just to require that it fully explicate the speaker's knowledge of the semantic structure of the language.

Let us start with the notion 'dictionary entry'. As we have seen above, a semantic theory is intended to reconstruct the process by which a speaker projects a meaning for a sentence from the meanings of the lexical items appearing in it. Thus, within a semantic theory the dictionary entries play the special role of providing the basis from which the projection rules of the theory derive the semantic interpretations that they assign sentences. Our characterization of the notion 'dictionary entry' must thus be such that in it we have a normal form for the dictionary entries which enables us to represent lexical information in a manner that is both formal and sufficient in content to provide a complete basis from which the projection rules can operate.

For the vast majority of cases,[10] a dictionary entry is a set consisting of a finite number of sequences of symbols, each sequence consisting of an initial subsequence of syntactic markers, followed by a subsequence of semantic markers, then, optionally, one distinguisher, and, finally, a selection restriction. Dictionary entries can be represented in the form of tree diagrams, such as that shown in Fig. XIV-2, in which each sequence in the entry for a lexical item m_i appears as a distinct path rooted at the lexical item m_i.[11] As illustrated in Fig. XIV-2, semantic markers are represented enclosed within parentheses, the distinguishers are represented enclosed within brackets, and the selection restrictions are represented within angles. Each complete path, each sequence, represents a distinct sense of the lexical item in whose entry it appears. Thus, in Fig. XIV-2 the lexical item bachelor is represented as having four distinct senses.

Semantic markers are the formal elements that a semantic theory employs to express semantic relations of a general nature. In contrast, distinguishers are the formal elements employed to represent that which is idiosyncratic about the meaning

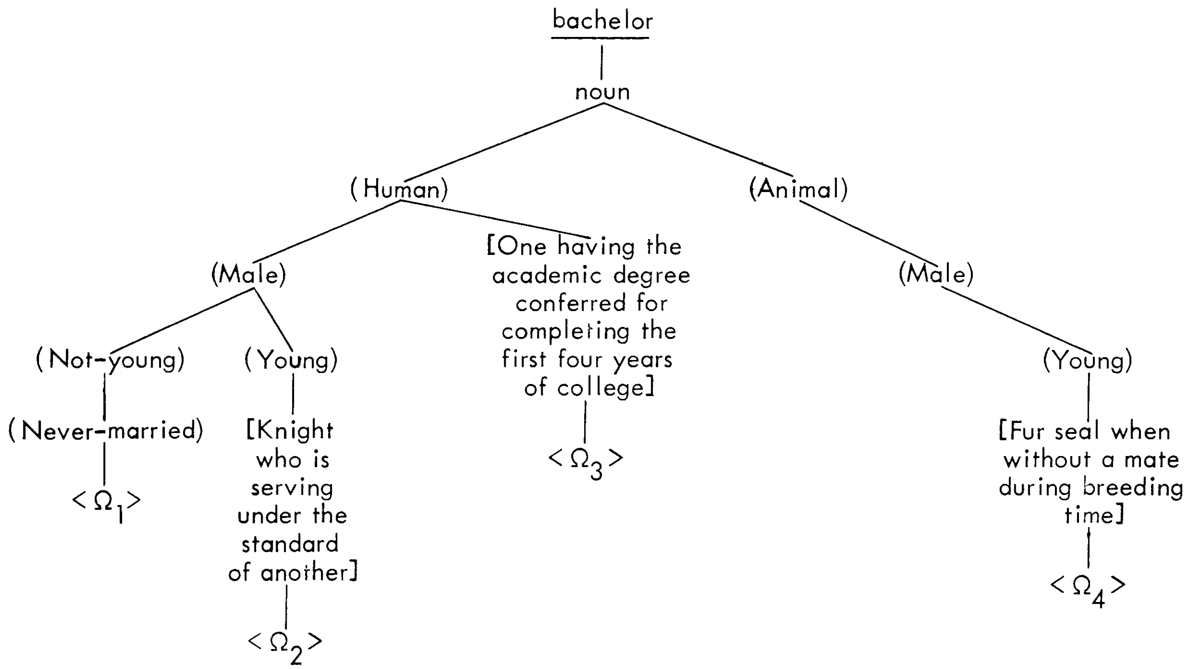


Fig. XIV-2.

of a lexical item. A distinguisher serves to distinguish a lexical item from those that are closest to it in meaning. Thus, a semantic marker found in the path of a certain lexical item will also be found in the paths of many other lexical items throughout the dictionary, whereas a distinguisher found in the path of a certain lexical item will, with very few exceptions, not be found anywhere else in the dictionary. This difference can be more fully appreciated if one compares the consequences of eliminating a semantic marker from a dictionary with the consequences of eliminating a distinguisher; in the former case indefinitely many semantic relations between the expressions of the language which were marked by the eliminated semantic marker would no longer be marked, whereas in the latter case only the few distinctions in sense which were marked by the eliminated distinguisher would no longer be marked.[12]

A lexical item is ambiguous if and only if its entry contains at least two distinct paths. It is clear, moreover, that ambiguity at the lexical level is the source of semantic ambiguity at the sentence level. Thus, a necessary, though not sufficient, condition for a syntactically unambiguous sentence to be semantically ambiguous is that it contain an ambiguous lexical item. For example, the source of the semantic ambiguity of the sentence He likes to wear a light suit in the summer is the lexical ambiguity of the word light. Since an adequate dictionary entry for a lexical item must mark every one of its ambiguities, the dictionary entry for light is required to represent this lexical item as branching into one path containing the semantic marker (Color) but not (Weight) and another containing the semantic marker (Weight) but not (Color).

However, an ambiguous lexical item in a syntactically unambiguous sentence is not a sufficient condition for that sentence to be semantically ambiguous. For example, the sentence *The stuff is light enough to carry*, though it contains the ambiguous lexical item *light*, is not understood according to the sense in which *light enough to carry* means light enough in color to be carried. Thus, that the occurrence of an ambiguous lexical item in a sentence does not *ipso facto* make that sentence semantically ambiguous implies that the grammatical relations in the sentence and/or the meanings of the other constituents prevent this item from bearing more than one of its readings in its role as a constituent of the sentence. This shows that selection of some senses and exclusion of others occur as a result of the other constituents of the sentence. Such selection is of fundamental importance because, together with lexical ambiguity, it determines whether or not a sentence is anomalous, whether a sentence is semantically unambiguous or semantically ambiguous, and all other semantic properties of sentences which we want a semantic theory to mark.

Therefore, besides containing syntactic markers that determine the part-of-speech classification for a lexical item, semantic markers that represent the semantic properties that the lexical item shares with many other lexical items, and (optionally) a distinguisher that fixes its idiosyncratic features, a path for a lexical item can contain selection restrictions that determine the combinations into which the lexical item can enter and the sense(s) that it bears in those combinations. The formal representation of selection restrictions can be regarded as an explication of such information as *The Shorter Oxford English Dictionary's* qualification that the word *honest* when applied to persons means "of good moral character, virtuous, upright" and applied to women is ambiguous between this sense and the sense of *chaste*. In SST we wrote:

> For our reconstruction, we shall use left and right angles enclosing a Boolian function of syntactic or semantic markers. Such configurations of symbols will be affixed to the terminal element of a path (either the distinguisher or the last semantic marker if there is no distinguisher) and will be construed, relative to the projection rules, as providing a necessary and sufficient condition for a semantically acceptable combination. Thus, for example, the angle-material affixed to the path of a modifier determines the applicability of *that* path of the modifier to a sense of a nominal head. In particular, a path in the dictionary entry for *honest* will be: *honest* → adjective → (Evaluative) → (Moral) – [Innocent of illicit sexual intercourse] <(Human) & (Female)>. This is to be construed as saying that an adjectival occurrence of *honest* receives the interpretation (Evaluative) → (Moral) → [Innocent of illicit sexual intercourse] just in case the head it modifies has a path containing both the semantic marker (Human) and the semantic marker (Female). How in actual practice a semantic theory utilizes angle-material to determine selection-exclusion relations to obtain the correct semantic interpretations for sentences can only be made clear by a statement of the projection rules.[13]

The next notion for us to explain is the notion 'projection rule'. Let us suppose that an English grammar provides a semantic theory with the input sentence The boys like candy, together with the constituent structure characterization as given in Fig. XIV-1. The first step that the theory performs in the process of assigning a semantic interpretation to this sentence will be to associate with each of the lexical items in the sentence, i.e., the, boy, s, like, and candy, all and only the paths from their dictionary entries that are compatible with the syntactic categorization that the lexical items are given in the constituent structure characterization. This is the first point at which a significant use of grammatical information is made, but by no means the last. The semantic theory works as follows: a path in the dictionary entry for the lexical item m_j is assigned to the finite, non-null set of paths P_j^i which is associated with the occurrence of m_j in the constituent structure characterization d_i just in case that path contains syntactic markers that attribute to m_j the same part-of-speech classification that it has on the constituent structure characterization d_i. Thus, the lexical item m_1 is associated with the set of paths P_1^i; m_2 is associated with P_2^i, ..., and m_n is associated with P_n^i.[14] Referring to Fig. XIV-1, we picture the result of this step as converting the diagram into one in which the is associated with the set of paths P_1^i, boy is associated with P_2^i, s is associated with P_3^i, like is associated with P_4^i, and candy is associated with P_5^i (though no other change is made). Thus, for example, P_5^i contains paths representing each of the senses that candy has as a noun but none of the paths representing its senses as a verb, e.g., We will candy fruits tomorrow, The fruits candy easily, etc. This rule that associates senses with the occurrences of lexical items in constituent structure characterizations is thus our first projection rule. But since it is in many ways atypical, we shall continue our discussion of projection rules as if this were not such a rule.

There are two types of projection rules: type 1 projection rules and type 2 projection rules. The job of type 1 projection rules is to effect a series of amalgamations of paths, proceeding from the bottom to the top of a constituent structure characterization, by embedding paths into each other to form a new path, the amalgam. The amalgam is then assigned to the set of paths associated with the node that immediately dominates the sets of paths from which the amalgamated paths were drawn. The amalgam thus provides one of the ways to read the sequence of lexical items that the node dominates. In this manner, a set of readings is provided for every sequence of lexical items dominated by a syntactic marker in the constituent structure characterization, until the highest syntactic marker 'S' is reached and associated with a set of readings for the whole sentence. The operation of amalgamation is that of joining with one another one path from each of the n different sets of paths dominated by a syntactic marker SM to form a composite path to be a member of the set of paths associated with the node that the syntactic marker SM labels. The joining of a pair of paths occurs just in case one of the paths satisfies the selection restrictions that the other contains. If the syntactic marker SM dominates just the sets of paths P^i_1, P^i_2, ..., P^i_n and P^i_1 contains k_1 paths, P^i_2 contains k_2 paths, ..., P^i_n contains k_m paths, then the set of paths which is associated with the dominating marker SM contains, at most $(k_1 \cdot k_2 \cdot \ldots \cdot k_m)$ members and possibly zero members if selection restrictions prevent every possible amalgamation from forming. Each path that is in the set assigned to SM is called 'a reading for the lexical string that SM dominates in the constituent structure characterization d_i'. The number of readings that is thus allotted to a string of lexical items determines its degree of semantic ambiguity: A string with no readings is anomalous, a string with exactly one reading is unambiguous, and a string with two or more readings is semantically ambiguous two or more ways.

An example of a projection rule of type 1 is:

(R1) Given two paths associated with nodes branching from the same node labelled SM, one of the form,

$\underline{\text{Lexical String}}_1 \rightarrow$ syntactic markers of head $\rightarrow (a_1) \rightarrow (a_2) \rightarrow \ldots \rightarrow (a_n) \rightarrow [1] <\Omega_1>$

and the other of the form,

$\underline{\text{Lexical String}}_2 \rightarrow$ syntactic markers of the modifier of the head $\rightarrow (b_1) \rightarrow (b_2) \rightarrow \ldots \rightarrow (b_m) \rightarrow [2] <\Omega_2>$

such that the string of syntactic or semantic markers of the head has a substring σ which satisfies $<\Omega_2>$, then there is an amalgam of the form,

$\underline{\text{Lexical String}}_2 + \underline{\text{Lexical String}}_1 \rightarrow$ dominating node marker SM $\rightarrow (a_1) \rightarrow (a_2) \rightarrow \ldots \rightarrow (a_n) \rightarrow (b_1) \rightarrow (b_2) \rightarrow \ldots \rightarrow (b_m) \rightarrow [[2][1]] <\Omega_1>$,

where any b_i is null just in case there is an a_j such that $b_i = a_j$, and $[[2][1]]$ is simply $[1]$ just in case $[2]=[1]$. This amalgam is assigned to the set of paths associated with the node labelled SM that dominates $\underline{\text{Lexical String}}_2 + \underline{\text{Lexical String}}_1$

(R1) explicates the process of attribution, i.e., the process of creating a new semantic unit compounded from a modifier and head whose semantic properties are those of the head, except that the meaning of the compound is more determinate than the head's by virtue of the semantic information contributed by the modifier. The erasure clause at the end of the statement of (R1) is included to avoid pointlessly duplicating the semantic markers and distinguishers in the path for a compound expression.[15] The modifier-head relation will be explicated by the grammar of the language so that the constituent structure characterization of a sentence will mark all cases of this relation that are found in it. In English, as well as many other languages, instances of modifier-head relations are: adjective-noun modification, adverb-verb modification, adverb-adjective modification, etc. Here, then, is another point at which grammatical information is utilized in the process of assigning a semantic interpretation to a sentence.

An example of an amalgamation produced by (R1) is the joining of the path <u>colorful</u>

→ adjective → (color) → [abounding in contrast or variety of bright colors] < (Physical object) v (Social activity) > and the path ball → noun → (Physical object) → [Of globular shape] to produce the new compound path colorful + ball → noun → (Physical object) → (color) → [[abounding in contrast or variety of bright colors][of globular shape]]. An example of an amalgamation that is prevented by a selection restriction is that of the path colorful → adjective → (Evaluative) → [of distinctive character, vividness, or picturesqueness] < (Aesthetic Object) v (Social Activity) > with the path for ball just given above. This possible amalgamation is precluded because the selection restriction in the path of the modifier requires that this path be joined only with paths of heads that contain either the semantic marker (Aesthetic object) or the semantic marker (Social activity), and this path of ball contains neither one of these semantic markers.

Type 2 rules work differently and are best explained after we explain the concept of a semantic interpretation of a sentence.

A semantic theory receives more than one constituent structure characterization for a sentence if that sentence is syntactically ambiguous. Figures XIV-3 and XIV-4 show the two constituent structure characterizations for the syntactically ambiguous sentence I like little boys and girls.

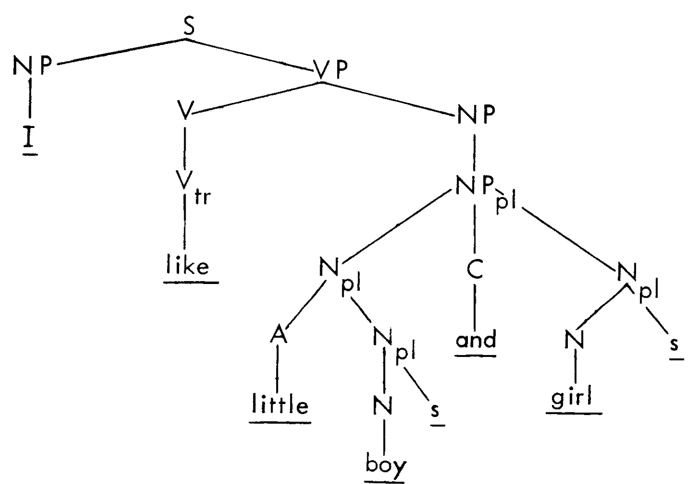


Fig. XIV-3.

Let d_1, d_2, ..., d_n (for $n \geq 1$) be the constituent structure characterizations that the grammar provides for the sentence S. We shall define the "semantic interpretation of S" to be (1) the conjunction $\psi d_1 \; \varepsilon \; \psi d_2 \; \varepsilon \; \ldots \; \varepsilon \; \psi d_n$ of the semantic interpretations of the n constituent structure characterizations of S, and (2) the statements about S that follow from the definition schema:

(D) S is <u>fully X</u> if and only if S is X on every d_i. The semantic interpretation ψd_i of the constituent structure characterization d_i of S is (1) the constituent structure characterization d_i each node of which is associated with its full set of readings, i.e., every reading that can belong to the set on the basis of the dictionary entries and the projection

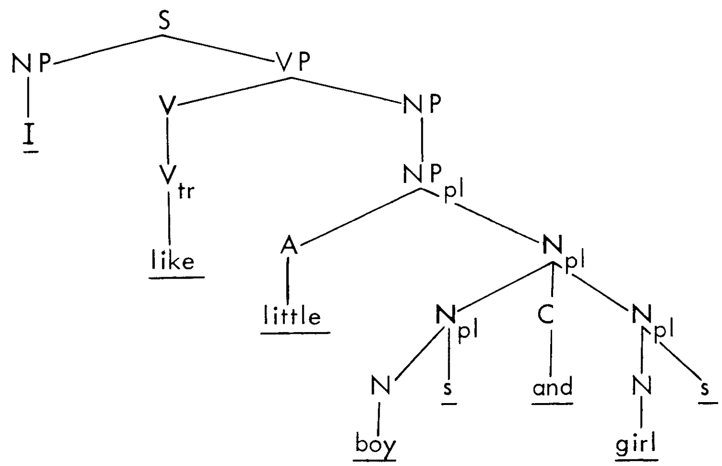


Fig. XIV-4.

rules does belong to it, and (2) the statements about S that follow from (1) together with the definitions:

(D1) S is <u>semantically anomalous on d_i</u> if and only if the set of paths associated with the node labelled 'S' in d_i contains no members.

(D2) S is <u>semantically unambiguous on d_i</u> if and only if the set of paths associated with the node labelled 'S' in d_i contains exactly one member.

(D3) S is <u>n-ways semantically ambiguous on d_i</u> if and only if the set of paths associated with the node labelled 'S' in d_i contains exactly n members ($n \geq 2$).

(D4) S_1 and S_2 are <u>paraphrases on a reading with respect to their characterizations d_i and d_j</u> if and only if the set of paths associated with the node labelled 'S' in d_i and the set of paths associated with the node labelled 'S' in d_j have a reading in common.

(D5) S_1 and S_2 are <u>full paraphrases with respect to their characterizations d_i and d_j</u> if and only if the set of paths associated with the node labelled 'S' in d_i and the set of paths associated with the node labelled 'S' in d_j have exactly the same membership.

Since these definitions are self-explanatory, we can now return to our account of the projection rules and explain the concept of a type 2 projection rule.

A grammar employs two types of syntactic rules to achieve its aim of assigning the correct constituent structure characterization to each sentence of the language.[16] The first type are rules that develop single symbols by rewriting operations that are restricted to scanning the linear context of the symbol to be developed for information used to determine the rule's applicability. Such rules construct constituent structure characterizations such as those in Figs. XIV-1, XIV-3, and XIV-4 in somewhat the following manner: the first rule rewrites the initial symbol S (standing for "sentence") as NP+VP (which categorizes a noun phrase-verb phrase sequence as a sentence), then a rule can be used to rewrite NP as either NP_{sing} or NP_{pl}, then other rules can be used to rewrite VP as either V+NP or V_{intr} or be+Pred, still other rules to rewrite NP_{sing} as T+N, T as <u>the</u>, N as <u>boy</u> (or <u>man</u>, <u>coat</u>, <u>mouse</u>, etc.), and so forth.[17] But the scanning limitation on these rules makes the second type of rule necessary, for it has been shown that a grammar can assign constituent structure characterizations correctly only if some of its rules use information about the derivational history of sentences in order to determine their applicability.[18] Thus, in addition to such rewrite rules, grammars contain what are called "transformational rules," rules that operate on entire constituent structure characterizations, or any of their parts, and map labelled trees onto labelled trees, thus transforming simpler sentences into more complex ones and assigning the transformed sentence a constituent structure characterization. Transformational rules perform the task of explicating the syntactic relations between sentence types in the language. Thus, they show the syntactic relation between such pairs as <u>The boys play games</u> and <u>Games are played by the boys</u>, <u>The men fly planes</u> and <u>What do the men fly?</u>, etc., by showing how the latter member of each pair is constructed out of the former.

Type 2 projection rules are intended to explicate the manner in which transformational rules preserve or change meaning. It has often been observed by linguists who work with transformational rules that the sentence resulting from the application of a transformational rule to a set of source sentences is related in meaning to these source sentences in a definite, systematic way.[19] The employment of type 2 rules is intended to reveal the facts of language that underlie this observation.

We can characterize a type 2 projection rule as a rule that produces a semantic interpretation ψd_i for the constituent structure characterization d_i that has been constructed by the operation of the transformation T out of the set of constituent structure characterizations $d_1, d_2, \ldots, d_n$. A type 2 projection rule operates on the set of semantic interpretations $\psi d_1, \psi d_2, \ldots, \psi d_n$ and the transformation T to produce the semantic interpretation ψd_i. Type 2 projection rules should assign semantic interpretations in such a way as to reconstruct the manner in which the meaning of the sentence that was constructed by T is a function of the meanings of each of the sentences that were used by T in its construction.

J. J. Katz

Footnotes

1. A full discussion of the nature of a semantic meta-theory will be found in J. J. Katz and J. A. Fodor, The structure of a semantic theory (to be published in Language); Readings in the Philosophy of Language, edited by J. A. Fodor and J. J. Katz (Prentice-Hall, Inc., Englewood Cliffs, N.J., in press).

2. This is not meant to imply that the conception of a semantic theory which is outlined here conceives of such a theory as the product of a discovery procedure.

3. Here, I anticipate some such objection as the following: "How can you say a fluent speaker 'knows' something if he cannot say what it is that you claim he knows?" I do not think anything hangs on my having the word "know," and so if anyone insists upon this objection, I shall give up the word rather than become embroiled in a lexical quibble. I intend to convey the idea that the fluent speaker has acquired the necessary means for performing a task whose character compels us to admit that its performance results from the application of rules. Among the reasons that compel us to make this admission is that cited by Miller, Pribram, and Galanter, viz. that the task of understanding any twenty-word sentence is one that a fluent speaker can perform, yet the number of twenty-word sentences is 10^{30}, while the number of seconds in a century is only 3.15×10^{9}. Cf. G. A. Miller, K. Pribram, and E. Galanter, Plans and the Structure of Behavior (Henry Holt and Company, New York, 1960), pp. 146-147.

4. I say "in principle" because, in practice, limitations of perception, memory, mortality, etc., prevent the speaker from applying his knowledge of the rules of the language to provide himself with the meaning of certain sentences. This situation is exactly analogous to the case of a person's knowledge of the rules of arithmetic computation. Knowing how to perform any computation and knowing the rules of arithmetic computation are not sufficient to enable someone to actually perform any (specific) computation; for, again, limitations of perception, memory, mortality, etc., stand in the way.

5. Such information will be needed to provide the difference upon which rests the distinction in meaning between sentences composed of exactly the same morphemes, e.g., Gourmets do approve of people eating, Gourmets do approve of eating people, Do gourmets approve of people eating?, and so on.

6. N. Chomsky, Syntactic Structures (Mouton and Company, 'S-Gravenhage, Second Printing, 1962), Chapter 4. In general, we shall follow Chomsky's conception of syntax.

7. I shall use the notational abbreviations: "NP" for a noun phrase, "VP" for a verb phrase, "N" for a noun, "V" for a verb, "T" for an article, "A" for an adjective, "C" for a co-ordinating conjunction, and the subscript symbols "sing," "pl," and "tr" for the syntactic properties of nominal singularness, nominal pluralness, and verbal transitivity, respectively.

8. In particular, an optimal grammar will include a specification of the transformational history for each sentence. Cf. N. Chomsky, op. cit.

9. For the first of these two examples I am indebted to Professor Uriel Weinreich, Columbia University, and for the second to Professor George A. Miller, Center for Cognitive Studies, Harvard University.

10. In a small minority of cases, dictionary entries consist of instructions, e.g., the rules for not that are given in J. J. Katz, Analyticity and contradiction in natural language, Readings in the Philosophy of Language, op. cit. For a further discussion of the type of entry found in the vast majority of cases see J. J. Katz and J. A. Fodor, op. cit., Section 6.

11. Two comments on Fig. XIV-2. First, the word bachelor, though a noun, can select and exclude other nouns in various types of constructions, e.g., in noun-noun cases such as He is my bachelor friend, or in noun-in-apposition cases such as Mr. Smith, the neighborhood bachelor, is here. Thus, we must represent bachelor as having a selection restriction for each sense; thus the terminal element for each path in Fig. XIV-2 is a selection restriction enclosed in angles. Second, the particular selection restrictions are omitted because their inclusion would only complicate matters unnecessarily at this point.

12. For a further examination of the distinction between the notions 'semantic marker' and 'distinguisher', see J. J. Katz and J. A. Fodor, op. cit., Section 6.

13. Ibid., loc. cit.

14. For a full discussion of this step see the treatment of rule (I) in Katz and Fodor, ibid., Section 7.

15. Thus, for example, it makes no sense to include the semantic markers (Human) and (Female) twice in the path associated with the compound spinster aunt because both of the constituent paths contain occurrences of both. The second occurrence of (Human) or (Female) would provide no semantic information whatever.

16. Although this is not the only aim of a grammar. Cf. N. Chomsky, On the notion 'rule of grammar', Proc. Symposia in Applied Mathematics, Vol. 12, The Structure of Language and Its Mathematical Aspects, edited by R. Jakobson (American Mathematical Society, New York, 1961), pp. 6-24.

17. Cf. N. Chomsky, A transformational approach to syntax, Third Texas Conference on Problems of Linguistic Analysis of English, edited by A. A. Hill (University of Texas, 1962), pp. 123-159.

18. N. Chomsky, Syntactic Structure, op. cit.; On the notion 'rule of grammar', op. cit.; The Logical Structure of Linguistic Theory, 1955 (microfilm available in Hayden Library, M.I.T.). Cf. P. Postal, Some further limitations of phrase-structure grammars, Readings in the Philosophy of Language, op. cit.

19. This point has been discussed outside the context of the conception of a semantic theory adopted in the present report in two recent papers: J. A. Fodor, Projection and paraphrase in semantics, Analysis 21, 73-77 (1961); J. J. Katz, A reply to 'Projection and Paraphrase in Semantics', Analysis 22, 36-41 (1961).

B. REMARKS ON THE MORPHOPHONEMIC COMPONENT OF RUSSIAN

In this report we present an entirely new synchronic analysis of the morphophonemic component of the contemporary standard literary dialect of Russian. Although our analysis is original, we nevertheless draw the reader's attention to the general similarity of the rules that we propose here and the rules already proposed by previous investigators.[1] The originality of our analysis, therefore, consists primarily in the underlying (phonemic) structure which we postulate for Russian.

We consider here only verb forms, and in the rules presented below we shall not dwell on particularities of pronunciation which have been adequately described elsewhere.[2]

We shall be concerned in particular with the following forms:

	Infinitive	1 Sg	3 Sg	3 Pl	Imperative	Masc Past
1.	n,ɪst,í	n,ɪsú	n,ɪs,ɔ́t	n,ɪsút	n,ɪs,ít,ɪ	n,ɔ́s
2.	t,éč,	t,ɪkú	t,ɪč,ɔ́t	t,ɪkút	t,ɪk,ít,ɪ	t,ɔ́k
3.	l,ub,ít,	l,ubl,ú	l,úb,ɪt	l,úb,ɪt	l,ub,ít,ɪ	l,ub,íl
4.	plákət,	pláč,u	pláč,ɪt	pláč,ut	pláč,t,ɪ	plákəl
5.	l,ɪžát,	l,ɪžú	l,ɪžɨ́t	l,ɪžát	l,ɪžɨ́t,ɪ	l,ɪžál
6.	znát,	znáju	znájɪt	znájut	znájt,ɪ	znál
7.	žɨ́t,	žɨvú	žɨv,ɔ́t	žɨvút	žɨv,ít,ɪ	žɨ́l
8.	abrəzavát,	abrazúju	abrazújɪt	abrazújut	abrazújt,ɪ	abrəzavál
9.	gl,ɪd,ét,	gl,ɪžú	gl,ɪd,ít	gl,ɪd,át	gl,ɪd,ít,ɪ	gl,ɪd,él

We assume the syntactic component of the grammar to produce the forms presented below. Parentheses indicate immediate constituent structure. We consider our task to be that of deriving the phonetic representations above from the phonemic representations presented below:

	Infinitive	1 Sg	3 Sg	3 Pl	Imperative	Masc Past
1.	(nes+tĪ)	((nes+e)+ou)	((nes+e)+t)	((nes+e)+out)	(((nes+e)+Ī+#)+te)[3]	(nes+l)
2.	(tek+tĪ)	((tek+e)+ou)	((tek+e)+t)	((tek+e)+out)	(((tek+e)+Ī+#)+te)	(tek+l
3.	(leub+Ī+tĪ)	((leub+Ī+Ī)+ou)	((leub+Ī+Ī)+t)	((leub+Ī+Ī)+ēt)	(((leub+Ī+Ī)+Ī+#)+te)	(leub+Ī+l)
4.	(plōk+ō+tĪ)	((plōk+ō+e)+ou)	((plōk+ō+e)+t)	((plōk+ō+e)+out)	(((plōk+ō+e)+Ī+#)+te)	(plōk+ō+l)
5.	(leg+ē+tĪ)	((leg+ē+Ī)+ou)	((leg+ē+Ī)+t)	((leg+ē+Ī)+ēt)	(((leg+ē+Ī)+Ī+#)+te)	(leg+ē+l)
6.	(znōi+tĪ)	((znōi+e)+ou)	((znōi+e)+t)	((znōi+e)+out)	(((znōi+e)+Ī+#)+te)	(znōi+l)
7.	(gĪu+tĪ)	((gĪu+e)+ou)	((gĪu+e)+t)	((gĪu+e)+out)	(((gĪu+e)+Ī+#)+te)	(gĪu+l)
8.	(obrōz+ou+ō+tĪ)	((obrōz+ou+ō+e)+ou)	((obrōz+ou+ō+e)+t)	((obrōz+ou+ō+e)+out)	(((obrōz+ou+ō+e)+Ī+#)+te)	(obrōz+ou+ō+l)
9.	(glēd+ei+tĪ)	((glēd+ei+Ī)+ou)	((glēd+ei+Ī)+t)	((glēd+ei+Ī)+ēt)	(((glēd+ei+Ī)+Ī+#)+te)	(glēd+ei+l)

One of the Morpheme-Structure Rules that we postulate for Russian states that no terminal vocabulary item may end in a vowel. This rule will convert terminal vocabulary items like /zn$\bar{o}$i/ and /g$\bar{i}$u/ to /zn$\bar{o}$j/ and /g$\bar{i}$w/. For the purposes of the present report we may state this MS-Rule as follows:

MS-1 $[-\text{cons}] \rightarrow [-\text{voc}]$ in env: ______ +

Note that because of this rule we may use archiphonemes specified solely for the features consonantal and gravity in terminal vocabulary items like /zn$\bar{o}$I/ and /g$\bar{i}$U/, etc.

In the phonemic forms presented above we have used the following vowel system:

segment:	$\bar{u}$	$\bar{i}$	$\bar{o}$	$\bar{e}$	u	i	o	e
tense:	+	+	+	+	−	−	−	−
diffuse:	+	+	−	−	+	+	−	−
grave:	+	−	+	−	+	−	+	−

We use consonant letters as abbreviations for the appropriate distinctive feature matrices. We draw attention, however, to the fact that in the forms presented above palatalization (sharping) of consonants is completely predictable (this fact may be formally presented in a Morpheme-Structure Rule to the effect that all consonants – with some limitations which we have discussed elsewhere – are specified non-sharp).

We require application of the following rules to the phonemic representation in order to derive the correct phonetic representations. C-Rules apply cyclically to segments within innermost parentheses; P-Rules apply to forms derived from the C-Rules.

C-1 Insert $\underline{j}$ in env: $\_\_\_\_ + \begin{bmatrix}+\text{voc}\\-\text{cns}\\+\text{tns}\end{bmatrix} + \begin{bmatrix}+\text{voc}\\-\text{cns}\\-\text{tns}\end{bmatrix}^4$

C-2 $\underline{u} \rightarrow \underline{w}$ in env: $\_\_\_\_ + \begin{bmatrix}+\text{voc}\\-\text{cns}\end{bmatrix}$

C-3 $V_1^2 \rightarrow \emptyset$ in env: $\_\_\_\_ + \begin{bmatrix}+\text{voc}\\-\text{cns}\end{bmatrix}$

C-4 Erase parentheses and return to C-1. If there are no more parentheses, then go to P-1.

P-1 $\begin{bmatrix}+\text{obs}\\+\text{cmp}\end{bmatrix} \rightarrow \begin{bmatrix}+\text{str}\\-\text{grv}\end{bmatrix}$ in env: $\_\_\_\_ \begin{bmatrix}+\text{voc}\\-\text{cns}\\-\text{grv}\end{bmatrix} X$

where X is not + # .

P-2 $[+\text{cons}] \rightarrow [+\text{sharp}]$ in env: $\_\_\_\_ \begin{bmatrix}-\text{cns}\\-\text{grv}\end{bmatrix}$

P-3 $\underline{\bar{i}} \rightarrow \emptyset$ in env: X + ($\underline{t}$,) ______ + #

where X contains a stressed vowel and does not end in two consonants.

P-4 Transitive softening (i.e., s, j → š, , d, j → ǰ, , b, j → bl, , k, j → č, , etc., and j → ∅ in env: C ____).

P-5 e → o in env: ____ $\begin{bmatrix}\text{+cons}\\ \text{-shrp}\end{bmatrix}$

P-6 X → $\begin{bmatrix}\text{-cmp}\\ \text{-flt}\end{bmatrix}$

P-7 $\begin{bmatrix}\text{-tns}\\ \text{+grv}\end{bmatrix}$ → [+flt]

P-8 [-dif] → [+cmp]

(P-6 – P-8) in env: $\begin{bmatrix}\overline{\text{+voc}}\\ \text{-cns}\end{bmatrix}$

P-9 ɛ ɪ → ɪ ɛ

P-10 V → ∅ in env: ____ V

P-11 w → v

P-12 $\left\{\begin{matrix}\check{s}, & \rightarrow & \check{s}\\ \check{j}, & \rightarrow & \check{z}\\ c, & \rightarrow & c\end{matrix}\right\}$

P-13 æ → a

P-14 Vowel reduction; raising of [ɛ́] to [é] before soft consonants; backing of [i] to [ɨ] after hard consonants.

P-15 $\begin{bmatrix}\text{-voc}\\ \text{-cns}\end{bmatrix}$ → ∅ in env: ____ + [+cons]

P-16 $\left\{\begin{matrix}d\\ t\end{matrix}\right\}$ → ∅ in env: ____ + l

P-17 l → ∅ in env: C + ____

P-18 Erase all boundary and juncture markers.

P-Rules 6-8 apply to all vowels and specify features absent in the matrix presented above. Note that after application of P-Rules 6-8 the vowel segments presented above will have the following distinctive feature matrices:

segment:	ū	ī	ō	ē	u	i	o	e
tense:	+	+	+	+	–	–	–	–
diffuse:	+	+	–	–	+	+	–	–
grave:	+	–	+	–	+	–	+	–
compact:	–	–	+	+	–	–	+	+
flat:	–	–	–	–	+	–	+	–

Inspection of this matrix will reveal that application of P-Rules 6-8 have the following effect (symbols to the left of the arrow those of the matrices above, to the right of the arrow those of the International Phonetic Alphabet):

ū	→	ɨ	u	→	ʊ
ī	→	i	i	→	ɪ
ō	→	a	o	→	ɔ
ē	→	æ	e	→	ɛ

We apply these rules to some of the phonemic forms presented above:

1a: (nes+tī́) →C-4→ nes+tī́ →P-2→ n,es+t,ī́ →P-14→ n,ɪs+t,í →P-18→ n,ɪst,í

1b: ((nes+é)+t) →C-4→ (nes+é+t) →C-4→ nes+é+t →P-2→ n,es,+é+t →P-5→ n,es,+ó+t →P-6, P-7, P-8→ n,ɛs,+ɔ́+t →P-14→ n,ɪs,+ɔ́+t →P-18→ n,ɪs,ɔ́t

1c: (nés+l) →C-4→ nés+l →P-2→ n,és+l →P-5→ n,ós+l →P-6, P-7, P-8→ n,ɔ́s+l →P-17→ n,ɔ́s

2a: (ték+tī) →C-4→ ték+tī →P-2→ t,ék+t,ī →P-3→ t,ék+t, →P-4→ t,éč, →P-6, P-8, P-14→ t,éč,

2b: ((tek+é)+t) →C-4→ (tek+é+t) →C-4→ tek+é+t →P-1→ teč+é+t →P-2→ t,eč,+é+t →P-5→ t,eč,+ó+t →P-6, P-7, P-8, P-14→ t,ɪč,+ɔ́+t →P-18→ t,ɪč,ɔ́t

2c: (((tek+e)+ī́+#)+te) →C-4→ ((tek+e+ī́+#)+te) →C-3→ ((tek+ī́+#)+te) →C-4→ (tek+ī́+#+te) →C-4→ tek+ī́+#+te →P-2→ t,ek,+ī́+t,e →P-6, P-8, P-14, P-18→ t,ɪk,ít,ɪ

3a: ((leub+ī+ī)+ou) →C-3→ ((leub+ī)+ou) →C-4→ (leub+ī+ou) →C-1→ (leubj+ī+ou) →C-3→ (leubj+ou) →C-4→ leubj+ou →P-2→ l,eub,j+ou →P-4→ l,eubl,+ou →P-10→ l,ubl,+ú →P-18→ l,ubl,ú

4a: ((plṓk+ō+e)+t) →C-1→ (plṓkj+ō+e)+t) →C-3→ ((plṓkj+e)+t) →C-4→ (plṓkj+e+t) →C-4→ plṓkj+e+t →P-2→ plṓk,j+e+t →P-4→ plṓč,+e+t →P-5→ plṓč,+o+t →P-6, P-7, P-8→ pláč,+ɔ+t →P-14→ pláč,+ɪ+t →P-18→ pláč,ɪt

4b: (((plṓk+ō+e)+ī+#)+te) →C-1→ (((plṓkj+ō+e)+ī+#)+te) →C-3→ (((plṓkj+e)+ī+#)+te) →C-4→ ((plṓkj+e+ī+#)+te) →C-3→ ((plṓkj+ī+#)+te) →C-4→ (plṓkj+ī+#+te) →C-4→ plṓkj+ī+#+te →P-2→ plṓk,j+ī+#+t,e →P-3→ plṓk,j+#+t,e →P-4→ plṓč,+#+t,e →P-6, P-8, P-14, P-18→ pláč,t,ɪ

5a: (leg+ḗ+l) →C-4→ leg+ḗ+l →P-1→ leǰ+ḗ+l →P-2→ l,eǰ,+ḗ+l →P-6, P-8→ l,ɛǰ,+ǽ+l →P-12→ l,ɛž+ǽ+l →P-13→ l,ɛž+á+l →P-14→ l,ɪž+á+l →P-18→ l,ɪžál

6a: (znṓj+tī) →C-4→ znṓj+tī →P-2→ znṓj+t,ī →P-3→ znṓj+t, →P-6, P-8→ znáj+t, →P-15→ zná+t, →P-18→ znát,

6b: (((znṓj+e)+ī+#)+te) →C-4→ ((znṓj+e+ī+#)+te) →C-3→ ((znṓj+ī+#)+te) →C-4→

(znṓj+ī́+##te) →C-4→ znṓj+ī́+##te →P-2→ znṓj+ī́+##t,e →P-3→ znṓj+##t,e
→P-6, P-8→ znáj+##t,ε →P-14→ znáj+##t,ɪ →P-18→ znájt,ɪ

8a: ((obrōz+ou+ō+e)+ou) →C-1→ ((obrōz+ouj+ō+e)+ou) →C-3→ ((obrōz+ouj+e)+ou)
→C-4→ (obrōz+ouj+e+ou) →C-3→ (obrōz+ouj+ou) →C-4→ obrōz+ouj+ou →P-6,
P-7, P-8→ ɔbraz+ɔuj+ɔu →P-10→ ɔbraz+új+u →P-14→ abraz+új+u →P-18→
abrazúju

8b: (obrōz+ou+ṓ+l) →C-2→ (obrōz+ow+ṓ+l) →C-4→ obrōz+ow+ṓ+l →P-6, P-7, P-8→
ɔbraz+ɔw+á+l →P-11→ ɔbraz+ɔv+á+l →P-14→ abrəz+av+á+l →P-18→ abrəzavál

9a: (glēd+ei+l) →C-4→ glēd+ei+l →P-2→ gl,ēd,+ei+l →P-6, P-8→ gl,æd,+εɪ+l
→P-9→ gl,æd,+ɪε+l →P-10→ gl,æd,+έ+l →P-14→ gl,ɪd,+έ+l →P-18→ gl,ɪd,έl

T. M. Lightner

References

1. We refer in particular to Roman Jakobson, Russian conjugation, Word 4, 155-167 (1948), M. Halle, Note on cyclically ordered rules in the Russian conjugation, Quarterly Progress Report No. 63, Research Laboratory of Electronics, M.I.T., October 15, 1961, pp. 149-155, T. M. Lightner, On pon,át, and obrazovát, type verbs in Russian, Quarterly Progress Report No. 67, Research Laboratory of Electronics, M.I.T., October 15, 1962, pp. 177-180, G. H. Matthews and T. M. Lightner, On the Present tense theme e/o in Russian, Quarterly Progress Report No. 68, Research Laboratory of Electronics, M.I.T., January 15, 1963, pp. 190-193.

2. See, e.g., rules P-4, P-9, P-10, P-12, P-14. Details on these rules may be found in the works cited above. Information on stress prediction can be found in Jakobson, op. cit., and Halle, op. cit.; in this report we simply mark the stress where it falls and do not attempt to add anything to the work of previous investigators. For a more detailed discussion on the monophthongization of Slavic diphthongs (condensed here in rules P-9 and P-10), see Roman Jakobson, Remarques sur l'évolution phonologique du russe comparée à celle des autres langues slaves, III et passim, Travaux du Cercle Linguistique de Prague (Jednota Československých Matematiků a Fysiků, Prague, 1929), and more recently, M. Halle, The Proto-Slavic diphthongs, Quarterly Progress Report No. 66, Research Laboratory of Electronics, M. I. T., July 15, 1962, pp. 296-297.

3. For the necessity of assuming a # juncture in the imperative, see Roman Jakobson, Russian conjugation, op. cit., and M. Halle, The Sound Pattern of Russian (Mouton and Company, The Hague, 1959), p. 67. Note that this rule will prevent application of P-15 to forms like /znáj+##t,ɪ/ (ultimately [znájt,ɪ]).

4. We must place a restriction on the application of rule C-1. The restriction formulated by Halle in his "Note on cyclically ordered rules in the Russian conjugation" will not satisfy us because we do not consider ždat', lgat', brat', etc. to be formed from nonsyllabic roots, but rather from the roots /gid/, /lug/, /bir/, etc. In order to prevent application of C-1 to these verbs, we intend to follow some variant of Halle's most recent suggestion that this information be listed in the Complex Symbol for monosyllabic roots containing the archiphoneme {i, u}. Note that we require the presence of this vowel not only in order to account for the derived imperfectives vyžidat', oblygat', vybirat', etc., but also to account for the derived nominals lož', vybor, etc. (we defer treatment of imperfective derivation and nominalization for a later report). We shall postulate a special marker in the Complex Symbol to signal retention of these lax, diffuse vowels in the present tense of brat' (beru), zvat' (zovu), drat' (deru), stlat' (stelju).

We require further that the verb sosat' (sosu, sosët, etc.) be derived from the root /sus/, not only to account for the lack of application of C-1 but also to account for the dialectal forms ssu, ssët, etc. See A. G. Preobraženskij, Ėtimologičeskij slovar' russkago jazyka (Columbia University Press, New York, 1951), II, 360, and Max Vasmer, Russisches etymologisches Wörterbuch (Carl Winter, Universitätsverlag, Heidelberg, 1953), II, 701.

C. TYPE 1 GRAMMARS AND LINEAR-BOUNDED AUTOMATA

Recently, Landweber[1] showed that the language accepted by a deterministic linear-bounded automaton, in the sense of Myhill,[2] can be generated by a type 1 grammar, in the sense of Chomsky.[3] Landweber's proof remains valid for a nondeterministic linear-bounded automaton. As the converse of Landweber's theorem, we have

THEOREM: The language generated by a type 1 grammar is accepted by a nondeterministic linear-bounded automaton.

Thus, we now have equivalent heirarchies: Turing machines, linear-bounded automata, pushdown storage, and finite automata on the one hand, and semi-Thue systems, type 1 grammars, type 2 grammars, and type 3 grammars, on the other. (For the first pair, see, for example, Davis[4]; for the last two pairs, Chomsky.[3,5])

The proof of the theorem will consist of three lemmas. Before stating the lemmas, we shall define a few notions. According to Chomsky,[3] a grammar is type 1 if each rule is of the following shape:

$$\phi A \psi \rightarrow \phi \omega \psi, \; l(A) = 1, \; l(\omega) \neq 0.$$

Here, $l(\phi)$ means the length of ϕ. We generalize his notion a bit, and understand a type 1 grammar to be a semi-Thue system in which each of its rules $\phi \rightarrow \phi'$ satisfies $l(\phi) \leq l(\phi')$. If, furthermore, (a) $l(\phi) = l(\phi')$ and ϕ' does not contain the S-symbol S, or (b) $\phi = S$, then the grammar is called length-preserving. On the other hand, we define the order of a grammar to be the maximum of the lengths of the strings appearing in the rules. If an order 2 grammar is length-preserving and if $S \rightarrow EF$ implies that $E = S$, it is said to be linear-bounded. Then we have the following lemmas.

LEMMA 1: For any type 1 grammar G, there exists an order 2 type 1 grammar G' equivalent to G: L(G) = L(G').

Here, L(G) means the language generated by G. Notice that, since an order 2 type 1 (in the above-mentioned sense) grammar is easily seen to be equivalent to an order 2 grammar that is type 1 in Chomsky's sense, our notion of type 1 grammar turns out to be equivalent to the notion of type 1 grammar in Chomsky's sense, as far as the equivalence of grammars is concerned.

LEMMA 2: For any order 2 type 1 grammar G', there exists a linear-bounded grammar G'' equivalent to G': L(G') = L(G'').

LEMMA 3: For any linear-bounded grammar G'', there exists a nondeterministic linear-bounded automaton that accepts L(G'').

Our theorem follows directly from these lemmas.

S. -Y. Kuroda

References

1. P. S. Landweber, Three theorems on phrase structure grammar of type 1, (unpublished).

2. J. Myhill, Linear Bounded Automata, WADD Technical Note No. 60-165, Wright-Patterson Air Force Base, Ohio, 1960.

3. N. Chomsky, On certain formal properties of grammars, Information and Control 2, 137-167 (1959).

4. M. D. Davis, Computability and Unsolvability (McGraw-Hill Book Company, New York, 1958).

5. N. Chomsky, Context-free grammars and pushdown storage, Quarterly Progress Report No. 65, Research Laboratory of Electronics, M.I.T., April 15, 1962, pp. 187-194.

D. FORMAL JUSTIFICATION OF VARIABLES IN PHONEMIC CROSS-CLASSIFYING SYSTEMS

Variables in phonemic rules have proved extremely useful.[1-3] There is also a clear formal necessity that variables be included in any system with cross-classificatory features (whether or not the features are binary). If variables were not cost-free with respect to a simplicity criterion, the segments [+compact], [+grave] would appear to be related to each other in a more fundamental sense than the segments [−compact], [+grave]. But it is only an arbitrary decision to measure frontness in terms of gravity. '+grave' is exactly equivalent to '−acute': the value of the polarity of a given feature quality is not a substantive part of the theory. Therefore the metatheory requires that the features in a cross-classifying system are all marked:

$$[O\,\alpha F]$$

$F \rightarrow$ grave
compact
⋮

$$\alpha \rightarrow \begin{Bmatrix} + \\ - \end{Bmatrix}$$

$$O \rightarrow \begin{Bmatrix} e \\ \sim \end{Bmatrix}$$ (by convention, the identity operation e is left blank)

with the operations $\sim + = -$ $\quad e+ = +$

$\sim - = +$ $\quad e- = -$

In phonemic matrices and nonvariable rules the value of O is usually affirmative, and α is specified with '+' or '-', but this is purely a convention; it would be exactly equivalent to maintain generally the value of $\alpha = +$ and specify the phonemic matrices by the symbols '$\sim$' or 'e'.

The availability of different operators clearly shows that the segments [+compact], [-grave] are in as close a relation as [+compact], [+grave]. For instance, the assimilation rules

[ ] → [+comp] in the env —— [+grave]
→ [-comp] in the env —— [-grave]

are more simply combined

A) [ ] → [αcomp] in the env —— [αgrave]

and the assimilation rules

[ ] → [-comp] in the env —— [+grave]
→ [+comp] in the env —— [-grave]

are combined

B) [ ] → [$\sim\alpha$comp] in the env —— [αgrave].

If the front quality of segments were marked with acuteness instead of gravity, rules A) and B) would be equally simple: only the polarity is changed

A') [ ] → [$\sim\alpha$comp] in the env —— [αacute]
B') [ ] → [αcomp] in the env —— [αacute].

The arbitrariness of the polarity values is represented by the existence of cost-free variables that make [+X] = [$\sim$-X'] where X and X' are opposite extreme values along the same feature continuum (e.g. {acute, grave; abstract, concrete}).

In phonology the use of variables over + and - and operators covers various phenomena:

<u>assimilation</u>

[ ] → [αX] in the env —— [αX]

<u>dissimilation</u>

[ ] → [$\sim\alpha$X] in the env —— [αX]

<u>internal assimilation</u>

[αX] → [αY]

<u>internal dissimilation</u>

[αX] → [$\sim\alpha$Y]

external environment specification

$[\quad] \rightarrow [+X] / \rule{1.5em}{0.4pt} [\alpha X] [\sim \alpha Y]$

exchange (internal dissimilation)

$[\alpha X] \rightarrow [\sim \alpha X]$

If the exchange rule applies in a transformational cycle, the net effect is one of reciprocation with respect to the feature X. If the affected segment is contained within an odd number of constituents to which the exchange rule applies, the net effect is dissimilative; if it applies an even number of times, there is no net effect. (Sections XIV-E, XIV-F, and XIV-G present the use of such a rule in the Indo-European e/o ablaut.)

T. G. Bever

References

1. M. Halle, A descriptive convention for treating assimilation and dissimilation, Quarterly Progress Report No. 66, Research Laboratory of Electronics, M. I. T., July 15, 1962, pp. 295-296; M. Halle, The Proto-Slavic diphthongs, Quarterly Progress Report No. 66, Research Laboratory of Electronics, M. I. T., July 15, 1962, pp. 296-297.

2. T. G. Bever, Theoretical implications of Bloomfield's "Menomini Morphophonemics," Quarterly Progress Report No. 68, Research Laboratory of Electronics, M.I.T., January 15, 1963, pp. 197-203.

3. T. M. Lightner, Vowel harmony in classical (literary) Mongolian, Quarterly Progress Report No. 68, Research Laboratory of Electronics, M. I. T., January 15, 1963, pp. 189-190.

E. THE RECIPROCATING CYCLE OF THE INDO-EUROPEAN E/O ABLAUT

The Indo-European (IE) e/o ablaut can be described by a reciprocating rule of the type discussed in Section XIV-D. The traditional presentation of the e/o ablaut is in terms of the cases, tenses or other derivations of the ablauting stems. An extremely telling observation is that words in compounds often have the opposite grade from the words alone.[1] This clearly indicates that the number of constituents in which the ablauting stem is contained is critical. In generative grammar, the combination of a morphophonemic cycle and an exchange rule is sensitive to the odd or even quality of the number of constituents. The IE rule is of the form

$[\alpha \text{grave}] \rightarrow [\sim \alpha \text{grave}]$

and it applies in a cycle. If the number of constituents containing the ablauting vowel is odd, the grade is changed; if it is even, the grade is unchanged. Sections XIV-F and XIV-G present the operation of this rule in Germanic and Greek. In the Germanic languages the scope of the ablaut is sharply restricted, but the similarity of the essential rule to that of Greek indicates that IE itself had a morphophonemic transformational cycle that generated the e/o ablaut alternations.

T. G. Bever, D. T. Langendoen

References

1. J. Kurylowicz, L'apophonie en Indo-Européen (Polska Akademia Nauk, Warsaw, 1956), p. 71.

F. THE E/O ABLAUT IN OLD ENGLISH

The Germanic reflex of the Indo-European e/o ablaut appears in the nonreduplicating strong stems. The Germanic strong verbs, by Grimm's definition, show stem-vowel changes in derived forms. This analysis follows Keyser's suggestion that the historical distinction between the strong and weak stems is operative in Old English: strong stems are phonemically monosyllabic; weak stems, polysyllabic.[1]

The Germanic nonreduplicating verb ablaut occurs in 6 classes that are traditionally presented as 6 "ablaut series," each containing four forms. Since each of the classes is phonemically distinct, the entire set of series can be generated by 5 basic rules. Each rule is concerned with a single change in quality or quantity. This set occurs in a morphophonemic transformational cycle.

The traditionally presented "principal parts" of the old Germanic strong verb are: present infinitive, preterite singular, preterite plural, and past participle.

1. Past Participle

The strong verb past participle throughout old Germanic is generated by the rules

$$\begin{bmatrix} +\text{voc} \\ -\text{cons} \end{bmatrix} \left\{ \begin{array}{l} \rightarrow \emptyset \text{ in the env } \underline{\qquad\quad} \begin{bmatrix} +\text{voc} \\ -\text{cons} \end{bmatrix} \\ \rightarrow [+\text{grave}] \text{ in the env } \underline{\qquad\quad} [+\text{sonorant}] \end{array} \right.$$

Although these rules can be combined with the strong stem cycle, they will be omitted to simplify this presentation.

The relevant constituent structure is described by the rules

$$\text{Verb} \rightarrow \text{stem (+extension)} - \text{Mood}$$

$$\text{Mood} \rightarrow \text{PerNo} + \left\{ \begin{array}{l} \text{indicative} \\ \text{subjunctive} \\ \text{infinitive} \\ \text{participle} \end{array} \right.$$

$$\text{PerNo} \rightarrow \left\{ \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \right\} \left\{ \begin{array}{c} \text{Sg} \\ \text{Pl} \end{array} \right\}$$

$$\text{Extension} \rightarrow \begin{Bmatrix} + \text{ substantive} \\ + \text{ past} \end{Bmatrix}$$

$$\left.\begin{array}{ll} \begin{Bmatrix} 1 \\ 3 \end{Bmatrix} & \text{sg} \rightarrow + \emptyset \\ \begin{Bmatrix} 1 \\ 2 \\ 3 \end{Bmatrix} & \text{pl} \rightarrow + \text{on} \end{array}\right\} \quad \text{in the env past} + \underline{\qquad}$$

In Germanic, the ablauting of strong stems is restricted to the past tense or the derivation of nouns. This is represented by the optional stem extension: the cyclic rules will apply to an extended strong stem only. The actual morphophonemic value of the /+past/ stem extension is not critical, although it is probably $\emptyset$. This interpretation is not proposed as an ultimate solution: it merely represents the fact that the occurrence of the ablaut is limited in Germanic.

The form of the stems to which the stem cycle applies is

$$(((\# \text{ stem} + \text{Ext}) + \begin{Bmatrix} \text{Sg} \\ \text{Pl} \end{Bmatrix}) + \#)$$

and in the cases presented here

$$(((\# \text{ stem} + \text{Ext}) + \begin{Bmatrix} \emptyset \\ \text{on} \end{Bmatrix}) + \#),$$

where /+ext/ has the value /+past/. In OE the rule

C-1) $[\alpha\text{grave}] \rightarrow [\sim\alpha\text{grave}]$ in the env $[\overline{\text{Long Syllable}}]$

is a reciprocating rule of the type discussed in Section XIV-E. Among the Germanic languages this rule is restricted to OE because only in OE does the distinction between /æ/ and /a/ "re-emerge" from reconstructed Proto-Germanic.

The environment "Long Syllable" is the same as that formulated by Keyser for the weak verb cycle[1]:

$$[+\text{cons}]\ [+\text{voc}]_{\alpha}\ [+\text{son}]_{\beta}\ [+\text{cons}],$$

where $\alpha + \beta \geq 2$.

The cycle reflects the historical verb class derivation,[2,3] since it is fairly clearly divided into two sections: the first 3 rules apply critically to the first 3 classes and the final 2 rules apply critically to the last 3 classes. The fact that all the environments are included between $\#C_0^3 \underline{\qquad} C$ blocks the application of rule C-1) to the vowel in /rid/ or /far/. It also blocks the application of rule C-4) to each vowel of /raad/ or the vowel of /band/ because rule C-4) is actually

$$[+\text{comp}]_1^1 \rightarrow [+\text{long}]_1^1 \text{ in the env } \#C_0^3 \underline{\quad} C + \text{ext} \begin{Bmatrix} \emptyset \\ +\text{on} \end{Bmatrix}$$

The effect of the environment /+ext $\emptyset$/ is to limit the application of rules C-4-b) and C-5) to the first cycle, when nothing follows the /+ext/.

One incorrect form is generated by these rules – the preterite singular of /beeodon/.

It comes out /baaæd/ instead of the correct form /bææad/, but the diphthong structure rules will correct this. In order not to violate the distinctness convention the diphthong structure rules need to be included at the beginning of the cycle.

The Old English Weak Verb Cycle

Rule	Pre-final restriction	Final restriction	
C-1) [αgrave] → [~αgrave] in the env		no restriction	C-1
C-2) [ ] → [+diff] in the env	$\}_1 \longleftrightarrow$ [+son] $\longleftrightarrow \{_1$	$+\begin{bmatrix}+\text{voc}\\-\text{cons}\end{bmatrix}$	C-2
C-3) $[\ \ ]_1^n \to \emptyset$ in the env	——— $\begin{bmatrix}+\text{voc}\\-\text{cons}\end{bmatrix}$	$+\begin{bmatrix}+\text{voc}\\-\text{cons}\end{bmatrix}$	C-3
C-4) $[+\text{comp}]_1^1 \to [+\text{long}]_1^1$ a) in the env		$+\begin{bmatrix}+\text{voc}\\-\text{cons}\end{bmatrix}$	C-4 a)
b) in the env		$\emptyset$	C-4 b)
C-5) [αcomp] → [~αcomp] in the env		$\emptyset$	C-5

All rules apply in the env $\begin{bmatrix}\overline{+\text{voc}}\\-\text{cons}\end{bmatrix}$, in extended strong stem only, i.e., the pre-final environment for rules C-1), C-2) is actually $\#C_0^3 \longleftrightarrow [+\text{son}]_1 \longleftrightarrow C_1$ +ext; for rule C-3): $\#C_0^3\ [\text{—}]_1^n \begin{bmatrix}+\text{voc}\\-\text{cons}\end{bmatrix} C_1$ +ext; and for rules C-4), C-5): $\#C_0^3\ [\text{—}]\ C_1$ +ext.

Low-level rules

p) Past → $\emptyset$

q) VV → $\overline{\text{V}}$

r) Diphthong structure: $[+\text{comp}]_3 \to [-\text{grave}]_2[+\text{grave}]$
(may be ordered before C-1)

Morphophonemically, long vowels are considered sequences of short vowels.

Class	Infinitive	Preterite Sg.	Preterite Pl.
1	rīdan	rād	ridon
2	bēodan	bǣad	budon
3	bindan	band	bundon
4	beran	bær	bǣron
5	metan	mæt	mǣton
6	faran	fōr	fōron

	−grave	+grave
+diffuse	i	u
{−diffuse, −compact}	e	o
+ compact	æ	a

OE Examples

(((# riid + ext) + ∅) + #)	Preterite Sg. – Class 1
(# ruud + ext)	C-1
(# raad + ext)	C-5
(# raad + ext + ∅)	New Cycle
(# rææd + ext + ∅ + #)	C-1
(# rææd + ext + ∅ + #)	New Cycle
(# raad + ext + ∅ + #)	C-1
# rād #	Low-Level Rules

(((# beeod + ext) + on) + #)	Preterite Pl. – Class 2
(# booed + ext)	C-1
(# baaæd + ext)	C-5
(# baaæd + ext + on)	New Cycle
(# bææad + ext + on)	C-1
(# biiud + ext + on)	C-2
(# bud + ext + on + #)	New Cycle
# budon #	Low-Level Rules

(((# bind + ext) + on) + #)	Preterite Pl. – Class 3
(# bund + ext)	C-1
(# band + ext)	C-5
(+ band + ext + on)	New Cycle
(# bænd + ext + on)	C-1
(# bind + ext + on)	C-2
(# bind + ext + on + #)	New Cycle
(# bund + ext + on + #)	C-1
# bundon #	Low-Level Rules

(((# met + ext) + on) + #)	Preterite Pl. – Class 4
(# mæt + ext)	C-5
(# mæt + ext + on)	New Cycle
(# mǣt + ext + on)	C-4
(# mǣt + ext + on + #)	New Cycle

OE Examples

(((# met + ext) + on) + #)	Preterite Pl. – Class 4
# mǣton #	Low-Level Rules
(((# far + ext) + ∅) + #)	Preterite Sg. – Class 5
(# fār + ext)	C-4
(# fōr + ext)	C-5
(# fōr + ext + ∅)	New Cycle
(# fōr + ext + ∅ + #)	New Cycle
# fōr #	Low-Level Rules

T. G. Bever

References

1. S. J. Keyser, The Old English Weak Verb Cycle, Paper presented at Linguistics Seminar, Research Laboratory of Electronics, M.I.T., February 1963.

2. J. Wright and E. Wright, Old English Grammar (Oxford University Press, London, 1914).

3. E. Prokosch, A Comparative Germanic Grammar (University of Pennsylvania, Philadelphia, 1939).

G. THE E/O ABLAUT IN GREEK

The well-known alternations between the vowels e and o in verbal roots in Greek can be predicted from the constituent structure of the words in which these roots appear and a rule of the form

$$\text{A.}\quad [\alpha\text{grave}] \rightarrow [\sim\alpha\text{grave}] \text{ in env } \begin{bmatrix} \overline{-\text{diffuse}} \\ -\text{compact} \\ -\text{cons} \end{bmatrix} X + Y\ (+\#) \text{ where } X, Y \text{ do not contain } \#$$

operating in a transformational cycle.

To show how this rule operates, we require a statement of the internal constituent structure of Greek verbs and of nominals derived from verbs. Despite all of the attention that linguists have paid to these forms in the past, no such formulation has ever been attempted for Greek. Consequently, the formulation that I present in this report below must be regarded as being highly provisional. To substantiate the claims that I make, or to refute them, we require a thorough statement of Greek syntax so that we can see how the rules embodying these claims fit into such a syntax.

1. Constituent Structure of the Verb

Ignoring for the moment the low-level selectional restrictions, the phrase structure of the Greek verb may be schematized by means of the following phrase structure rules:

P1. $V \rightarrow$ (Augment) V_{base} Person Number (Voice)

P2. $V_{base} \rightarrow V_{stem}$ Theme (Mood)

P3. $V_{stem} \rightarrow V_{root}$ (Tense)

P4. Voice $\rightarrow$ Middle

P5. Mood $\rightarrow \begin{Bmatrix} \text{Imperative} \\ \text{Optative} \\ \text{Subjunctive} \end{Bmatrix}$

P6. Tense $\rightarrow \begin{Bmatrix} \text{Present} \\ \text{Future} \\ \text{Aorist} \\ \text{Perfect} \\ \text{Passive (Future)} \\ \text{Aorist-Passive} \end{Bmatrix}$

When the voice constituent is missing, the verb is said to be in the active voice; without the mood constituent it is in the indicative mood, and without the tense constituent, it is in the second aorist tense and the augment constituent must be present. Only certain verbs can appear in the second aorist. In a complete Greek grammar, we shall probably want to introduce the constituents person, number, voice, and mood transformationally, but the statement given here is adequate for our purposes. We also ignore the problems of how to handle the "primary" and "secondary" person endings of the active voice, and the person endings in the perfect tenses.

The theme constituent is missing in certain tenses of certain verbs: for example, in the present tense of verbs whose present tense constituent is nu. This constituent is also missing in the perfect middle of all verbs; its absence here can be handled by the following deletion transformation:

T1. $\underset{1}{\text{Perfect}} \quad \underset{2}{\text{Theme}} \quad \underset{3}{X} \quad \underset{4}{\text{Middle}} \rightarrow 1 \quad 0 \quad 3 \quad 4$

The perfect constituent then permutes with the verbal root:

T2. $\underset{1}{V_{root}} \quad \underset{2}{\text{Perfect}} \rightarrow 2 \quad 1$

An additional constituent is then inserted after the root in the perfect active:

T3. $\underset{1}{\text{Perfect}} \quad \underset{2}{V_{root}} \quad \underset{3}{\text{Theme}} \rightarrow 1 \quad 2{+}K \quad 3$

The constituents K and perfect are rewritten in the morphophonemics by the rules:

M1. $K \rightarrow \begin{Bmatrix} \text{k in env } \left([-\text{cons}]\right)V_{root} + \underline{\qquad} \\ \varnothing \end{Bmatrix}$

$$\text{M2. Perfect} \rightarrow \begin{cases} \text{a) e} & \text{in env} \;\underline{\quad}\; + \begin{bmatrix} +\text{cons} \\ \alpha\text{vocalic} \end{bmatrix}_2 \\ \text{b) Ce} & \text{in env} \;\underline{\quad}\; + C_1^1 \\ \text{c) VCV} & \text{in env} \;\underline{\quad}\; + \begin{bmatrix} -\text{cons} \\ -\text{diffuse} \end{bmatrix} C_1^1 \\ \text{d) V} & \text{in env} \;\underline{\quad}\; + V \end{cases}$$

Note that rule M2-c gives the "Attic reduplication."

Given this apparatus, we are able to predict the vocalism of verbal roots in e: we expect e-vocalism throughout the conjugation except in the perfect active tenses of verb roots that end in one or more consonants. Following the nomenclature of traditional Germanic grammars, we shall call such roots strong; roots that end in vowels, we shall call weak. Thus consider the conjugation of the verb from the strong verbal root streph, 'twist, turn': (we conjugate in the first person plural throughout)

1. Present active (#(((+streph + ∅)+e)+men)+#): stréphomen
2. Future active (#(((+streph + s)+e)+men)+#): strépsomen
3. Perfect active (#(((+e+streph)+e)+a+men)+#): estróphamen
4. Pluperfect active (#(+e((+e+streph)+e)+e+men)+#): ēstróphemen
5. Perfect middle (#(+e+streph)+metha)+#): estrámmetha

The a-vocalism in the perfect middle is a consequence of the zero-grade or vowel deletion rule, which I have not formulated here. Where we find full-grade in perfect middles of strong roots in e, we find the e-vocalism; thus for the root leip, 'leave', we have

6. Perfect middle (#(+le+leip)+metha)+#): leleímmetha

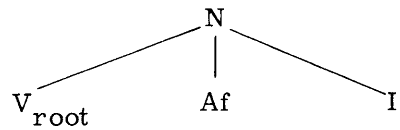
The conjugation of the weak verbal root kheu, 'pour' is exactly parallel to that of streph, except that in the perfect active tenses, the morpheme k given by rule M1 is present and the e-vocalism is maintained:

7. Perfect active (#(((+khe+kheu+k)+e)+a+men)+#): kekheúkamen.

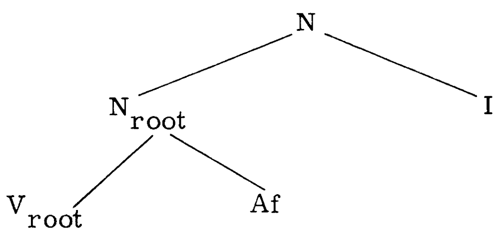
Since the only form in which rule A applies an odd number of times to the vowel of the verbal root is in the perfect active tenses of strong verbs, only there do we find the o-vocalism in the root. In every other form it operates an even number of times; twice in the perfect middle and four times elsewhere.

2. Constituent Structure of Nominals Derived from Verbal Roots

It seems reasonable to suppose that the derivation of nominals from verbs in Greek is merely a special case of generalized transformations that embed into noun or adjective phrases deformations of full sentences in which the verb appears. The verbal root, together with a derivational affix, becomes the head noun or adjective in the phrase. The resulting noun must obtain a grammatical gender, and presumably it gets it from derivational affix. I claim, for the moment without justification, that neuter and common gender affixes behave differently from affixes that are inherently feminine or masculine (by common gender affix, I mean an affix that is not inherently either masculine or feminine, but, depending on the derived word, it takes on one or another of these genders). The derived constituent structure of nouns having the first type of derivational affix is



where I is the inflectional suffix, supplied transformationally, which marks the case and number of the noun. Nouns formed with the second kind of derivational affix have the structure



The neuter derivational affixes are es and mat: the common gender affixes are the agentive affixes tēr and tor; inherently feminine affixes are ā, id, and ad; inherently masculine affixes are o and eu. Given this derived structure, we are immediately able to account for the vocalism in derived nouns from verbal roots in e: derived neuter and agent nouns will have e-vocalism, whereas derived feminine and masculine nouns formed from the affixes just listed will have o-vocalism as illustrated by the following examples, in which we use the roots streph and blep, 'look':

8.	(#(+streph+mat+os)+#)	:	strémmatos, 'a twist'	Genitive singular
9.	(#(+blep+es+os)+#)	:	blépeos, 'a look'	
10.	(#(+streph+ter+os)+#)	:	streptêros, 'anything which turns'	
11.	(#((+streph+o)+s)+#)	:	stróphos, 'a band'	Nominative singular
12.	(#((+streph+eu)+s)+#)	:	stropheús, 'a vertebra'	
13.	(#((+streph+ā)+∅)+#)	:	strophā́, 'a turning around'	
14.	(#((+streph+id)+s)+#)	:	strophís, 'a girdle'	
15.	(#((+streph+ad)+s)+#)	:	strophás, 'a circling'	

Weak verb roots that end in diffuse vowels also form derived nouns with the same ablaut relationship. For example, from the root kheu

16.	Genitive singular	(#(+kheu+mat+os)+#)	:	kheúmatos, 'a stream'
17.	Nominative singular	(#(+kheu+o)+s)+#)	:	khóos, 'a liquid measure'

18. Nominative singular (#(kheu+ā)+∅)+#) : khoā́, 'a libation'

and from the root dei, 'fear'

19. Genitive singular (#(+dei+es+os)+#) : déeos, 'fear'

3. Extent of Ablaut in Greek

Verbal roots with fundamental vocalism o rather than e do not undergo ablaut. Thus, although the verbal root kop 'strike' is strong, the vocalism of the perfect is not different from that of the other tenses; the present active is kóptomen, and the perfect active is kekóphamen. Similarly, all nouns derived from this root have an o-vocalism: for example, kómmatos, genitive singular, 'that which is struck'; kópos, nominative singular, 'a striking'; and kopís, nominative singular, 'a chopper'. Furthermore, all pure noun roots never exhibit ablaut. Certain derivational and inflectional endings, however, do show it, and in those cases in which it appears, it can be handled by rule A as before. For example, the neuter affix es appears as os in the nominative and accusative singular. But since there is a rule in Greek which deletes the nominative and accusative singular marker in all neuter nominals not formed with the affix o, this alternation follows immediately from rule A. Consider the nominative and accusative singular of forms 9 and 19:

20. (#(+blep+es)+#) : blépos

21. (#(+dei+es)+#) : déos

The masculine affix o of examples 11 and 17 appears as e in the vocative singular because the vocative singular marker has been deleted, so that rule A applies one less time to it. The affix eu, however, does not change in the vocative singular.

The theme of the verbal conjugation, which we have written e, also undergoes ablaut, but rule A alone cannot give the correct results. If, however, we suppose that there is also a low-level phonetic rule in Greek,

$$e \rightarrow o \quad \text{in env} \_\_\_ + [+\text{nasal}],$$

then the alternations of the theme vowel can be handled.

It is convenient, then, to set up a class of ablauting vowels in Greek: the e of verbal roots, and the vowels of certain inflectional morphemes. We are not forced, however, to mark the distinction between ablauting and nonablauting vowels phonemically; we require only a morphophonemic rule that will specially mark the ablauting vowels, and an adjustment to rule A which will allow it to operate only on those vowels that are so marked.

I am at present working on a system of rules which will account for the loss of vowels in certain positions (the zero-grade phenomenon), vowel lengthening, and accent placement. This entire system is also, apparently, part of the transformational cycle in Greek.

D. T. Langendoen